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entitled

# INVESTIGATION OF THE UNSTEADY PRESSURE DISTRIBUTION ON THE BLADE OF AN AXIAL FLOW FAN





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## INTRODUCTION

A major source of the noise generated by high bypass ratio aircraft fan engines is the unsteady pressures (and, hence, forces and moments) acting on the fan blades. These unsteady pressures are the result of the interaction of the blades with the wakes of upstream blade rows, inlet flow distortions, and inlet turbulence. To attempt reduction of the level of generated noise, it is necessary to know how the unsteady pressures, forces, and moments on the fan blades vary as a function of blade geometry and operating conditions - rotational speed, solidity, stagger angle, steady load, stage spacing, etc. The purpose of the research conducted under NASA Grant NGR 39-009-275 is to develop an experimental system which will permit the measurement of the unsteady pressure distributions on the blades of an axial flow turbomachine, to conduct a series of experiments to investigate these effects, and to compare the results with predictions from existing theoretical analyses.

This report is the fourth report of progress under NASA Grant NGR 39-009-275. The effort during this period has concentrated on the fabrication of an instrumented stator blade, its assembly with the pitran sensors, conducting an initial series of tests, and the reduction and analysis of test data.

## INSTRUMENTATION TO MEASURE UNSTEADY PRESSURES

In the development of an instrumented blade for the measurement of chordwise unsteady pressure distributions in an axial flow fan stage, there are a multitude of factors which must be considered. These include: the selection of a sensor; the mounting of the sensor in the blade; the distribution of sensors along the blade chord; the dynamic calibration of the mounted sensor; and analysis of the time-varying signal. By

initially concentrating on the development of a system for a stator blade, the additional problems which arise when considering a rotating blade, i.e., centrifugal effects and signal transfer from a rotating to stationary reference frame, are avoided.

After a review of commercially available dynamic pressure transducers, the STOW LABORATORIES, INC. PITRAN differential pressure transducer was selected as the sensor to be employed in this program. The advantages of this sensor are its size, .559 cm diameter; its sensitivity, 2.0 volts maximum output; and an overload tolerance of nearly 700 percent. The major disadvantage of the PITRAN is the drift which occurs in the output signal because of ambient temperature fluctuations. This problem can be corrected, however, by proper conditioning of the signal with an electronic feedback system provided by STOW LABORATORIES.

The blades of the AFRF test stage have a chord length of 15.24 cm, a maximum thickness of 1.524 cm at the 33% chord position, and a span length of 15.24 cm. To improve the spatial resolution of the measured pressure, each sensor is mounted internally facing a cavity with connecting taps to both surfaces of the blade, Figure 1. In this way, the unsteady pressure on each surface can be determined by alternately sealing one surface, or the differential pressure can be recorded by testing with both taps open. The cavity/surface tap method is more advantageous than the use of flush-mounted sensors because of the difficulty in fabricating a truly flush sensor. This is particularly true in the case of a curved surface. The design of the cavity/sensor mounting arrangement, has been discussed in previous Semi-Annual Reports [1].

The final configuration of one of the instrumented stator blade is

shown in Figure 2. This blade has six chordwise pressure taps located at the 5, 15, 30, 40, 50, and 75 percent chord positions with openings to both surfaces of the airfoil. The surface taps are distributed radially over a 2.54 cm segment centered at the mean radius of the blade in order to minimize flow interference from the upstream surface taps. Two additional instrumented blades have been constructed with pressure taps at the 2, 40, and 80.8 percent chord positions. These blades are restricted to measurement of the unsteady pressure on alternate surfaces i.e., one blade contains taps to the pressure surface and the other blade contains taps to the suction surface, because of the complexities in fabricating a tube passage from the surface to the cavity near the leading and trailing edges. The intent in utilizing these three blades is to provide pressure measurements at eight chordwise positions from which the minimum required number and location of surface taps necessary to provide an accurate measurement of the unsteady pressure distribution can be determined. The instrumented rotor blade will then be designed employing this optimized number and location of pressure taps.

## EXPERIMENTAL SET-UP AND DATA REDUCTION

The instrumented stator blade shown in Figure 2 was installed in the AFRF at a location approximately two chord lengths downstream of the stage rotor. The rotor configuration consisted of 12 rotor blades having the same symmetrical cross section as the stator, and a stagger angle of 45 degrees at the mean radius. This rotor is designed to operate at zero incidence along its entire span in a uniform flow, thus producing no energy transfer to the fluid. However, viscous effects within the blades introduce some fluid turning, approximately 3.0 degrees, at the design condition.

The interaction of the wakes from the upstream rotor with the instrumented stator result in unsteady pressure fluctuations at a fundamental frequency equal to the product of the number of rotor blades and the rotor rotational speed. The exact description of the wakes at the stator inlet was obtained by analyzing the output of a hot-film probe and a wedge-type yaw probe located at the duct mean radius. The mean flow angularity was first determined from the yaw probe output. The hot-film probe was then aligned perpendicular to the absolute mean flow direction, and the instantaneous wake velocity distribution was then recorded on magnetic tape in the form of the hot-film output. Simultaneously, the output of the PITRAN pressure transducers and the output of a photocell which emitted a single pulse for each revolution of the test rotor were recorded on magnetic tape.

Variations in the stator disturbance flow field were obtained by operating the stage rotor at a fixed rotational speed with three different throughflow velocities. At the rotor mean radius, these conditions correspond to rotor inlet incidence angles of 0, 5, and 10 degrees.

In addition to the dynamic calibration [1] of the cavity/sensor combination, each sensor was statically calibrated to determine its sensitivity (psi/volt). This was accomplished using a micromanometer which allows a precise pressure level to be set. One side of the differential sensor was then instantaneously subjected to this pressure while the other side was held at atmospheric pressure. The time history of the sensor output was then recorded on an oscillograph, which allowed the maximum voltage output to be determined.

Data analysis at each test condition was based on a total of 500 samples of the taped sensor or hot-film output which were digitized and

phase-lock averaged, using the photocell output as a trigger. Each data sample contained 512 points with a time increment between points of 0.0002 sec. The time duration of the digitizing process, 0.1024 sec, exceeded the rotor revolution period in all cases. The portion of this averaged signal which corresponded to the time for one rotor revolution, starting with the photocell pulse as time zero, was then Fourier analyzed to define the sensor/film output -- both magnitude and phase angle -- associated with the frequencies which correspond to integer multiples of the rotor blade passing frequency. The usual purpose of phase-lock averaging is to extract a periodic signal that is obscured by the presence of noise. The signals analyzed here were not of this type; however, the process was used to assure elimination of the effects of response of random sources of excitation, such as mechanical vibration and turbulence.

## EXPERIMENTAL RESULTS

An initial series of measurements have been completed with the instrumented stator blade having six pressure transducers/taps located at the 5, 15, 30, 40, 50 and 75 percent chord positions. Measurements were conducted of the time variation of pressure on each side of the blade with the opposite surface tap blocked, and of the differential pressure with both surface taps open. At the present time, these data are only partially analyzed and measurements at the 2 and 80.8 percent chord locations have not been conducted. As a result, it is not possible, at this time, to specify an optimum chordwise distribution of surface taps, or to present a comparison of the measured data with theoretical predictions. The results have demonstrated, however, that the PITRAN pressure transducers do function properly in the cavity

mounting arrangement employed here, and that a satisfactory response to the rotor wakes can be obtained.

Consider a test condition in which the rotor blades operate at zero angle of incidence. If the signal from the hot-film probe is averaged for 1-, 100-, and 500 sums, the wake velocity distribution as a function of time appears as shown in Figure 3. These data demonstrate the significance of phase-lock averaging in the separation of a random and periodic signal. They also show the existence of significant random fluctuations of the wake velocity. These random velocity fluctuations result in the broadband noise present in a fan's radiated noise spectrum, while the periodic velocity fluctuations give rise to the pure tone noise.

The magnitude of the periodic velocity fluctuations is quite small, ±2.8 percent of the mean volocity. The corresponding variation in sensor output voltage on one side of the blade as a function of time after 500 sums is shown in Figure 4 for the 5, 15, 30, and 50 percent chord surface tap locations. The output of each sensor must be multiplied by the sensor sensitivity, which is different for each location, in order to arrive at the static pressure fluctuation as a function of time. While the velocity fluctuations and, hence, the pressure fluctuations are very small, the sensor system is capable of reproducing the signal. Experiments at smaller rotor-stator spacing would result in a larger velocity fluctuation and, hence, larger pressure fluctuations.

## FUTURE EFFORTS

The experimental data obtained to date with the instrumented stator demonstrate that the sensors and their cavity/surface tap mounting arrangement are functioning properly. Further experiments will be con-

ducted in the near future, in which the unsteady pressures at the 2 and 80.8 percent chord locations will be determined. By combining these results with the measurements at the intermediate locations, the minimum number of sensors and their locations, which are required to adequately define the unsteady pressure distribution, will be determined. This information will then be employed in designing an instrumented rotor blade.

Additional experiments with the instrumented stator blade are scheduled to be conducted in November. As a result of the initial tests several modifications will be made to the instrumented blade and its associated electronics to improve the quality of the data and the required test time. These modifications included: (1) the use of O-ring seals around the PITRAN sensor to replace the washer/vacuum grease seal shown in Figure 1, (2) the determination of the PITRAN sensitivity after it has been mounted in the blade and (3) the procurement of an additional signal conditioning package thus eliminating the need for switching the electronics from sensor to sensor during a test.

References:

[1] Semi-Annual Progress Report (March 1974 to September 1974) on NASA Grant NGR 39-009-0275, October, 1974.

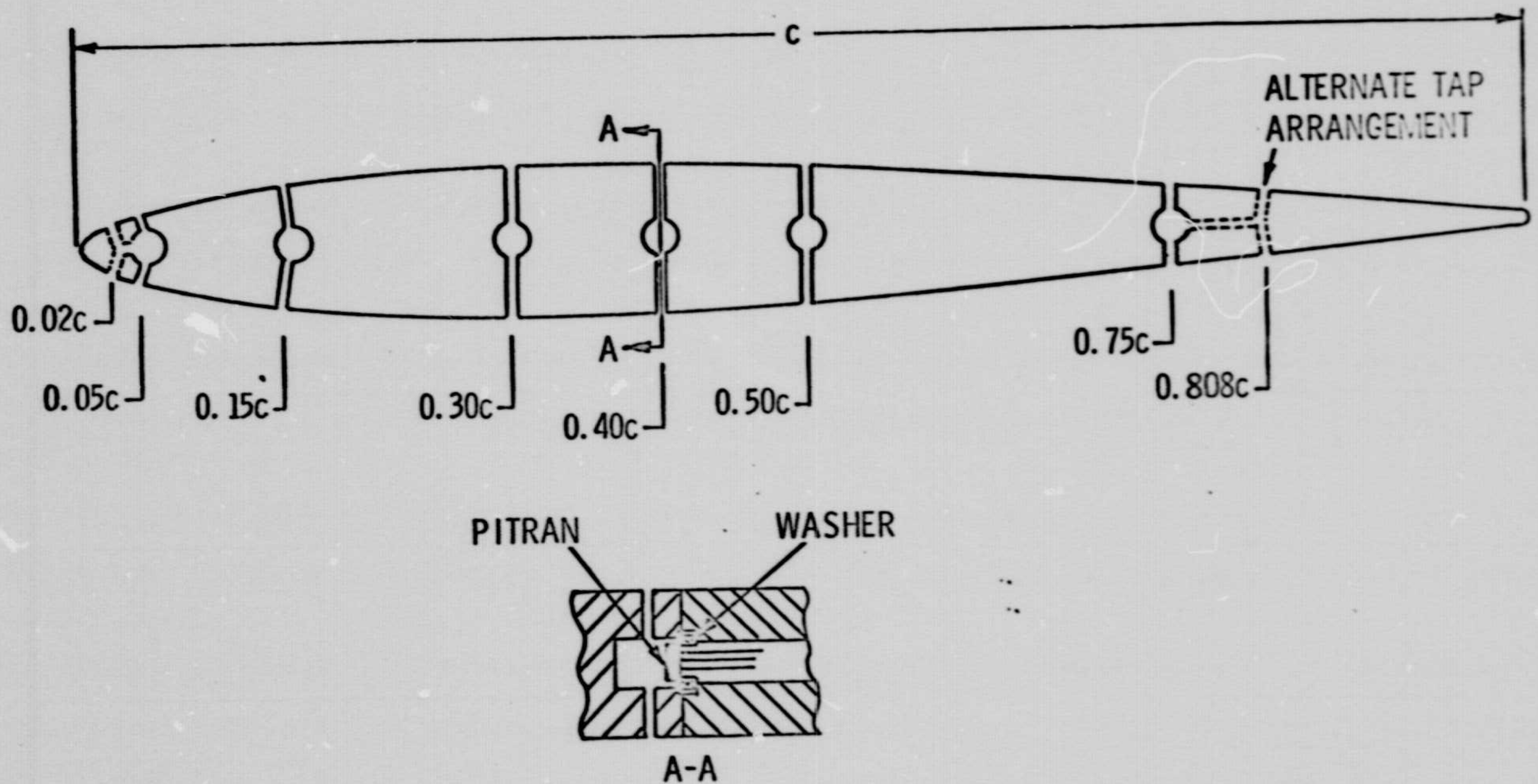


Figure 1: Illustration of Sensor Mounting Technique and Chordwise Distribution of Sensor Locations

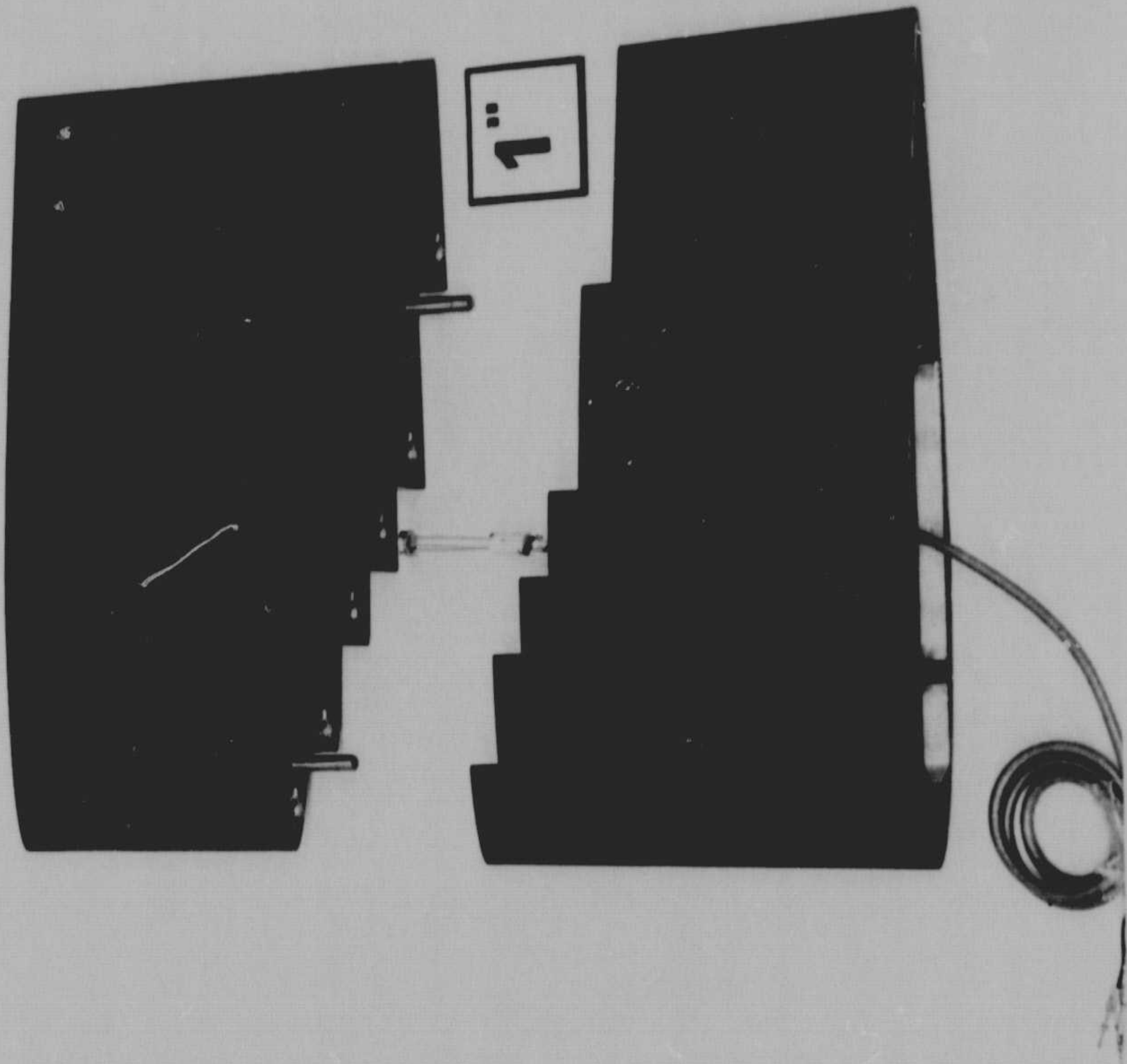


Figure 2: Exploded View Showing Internal Details
and One of the Six Sensors

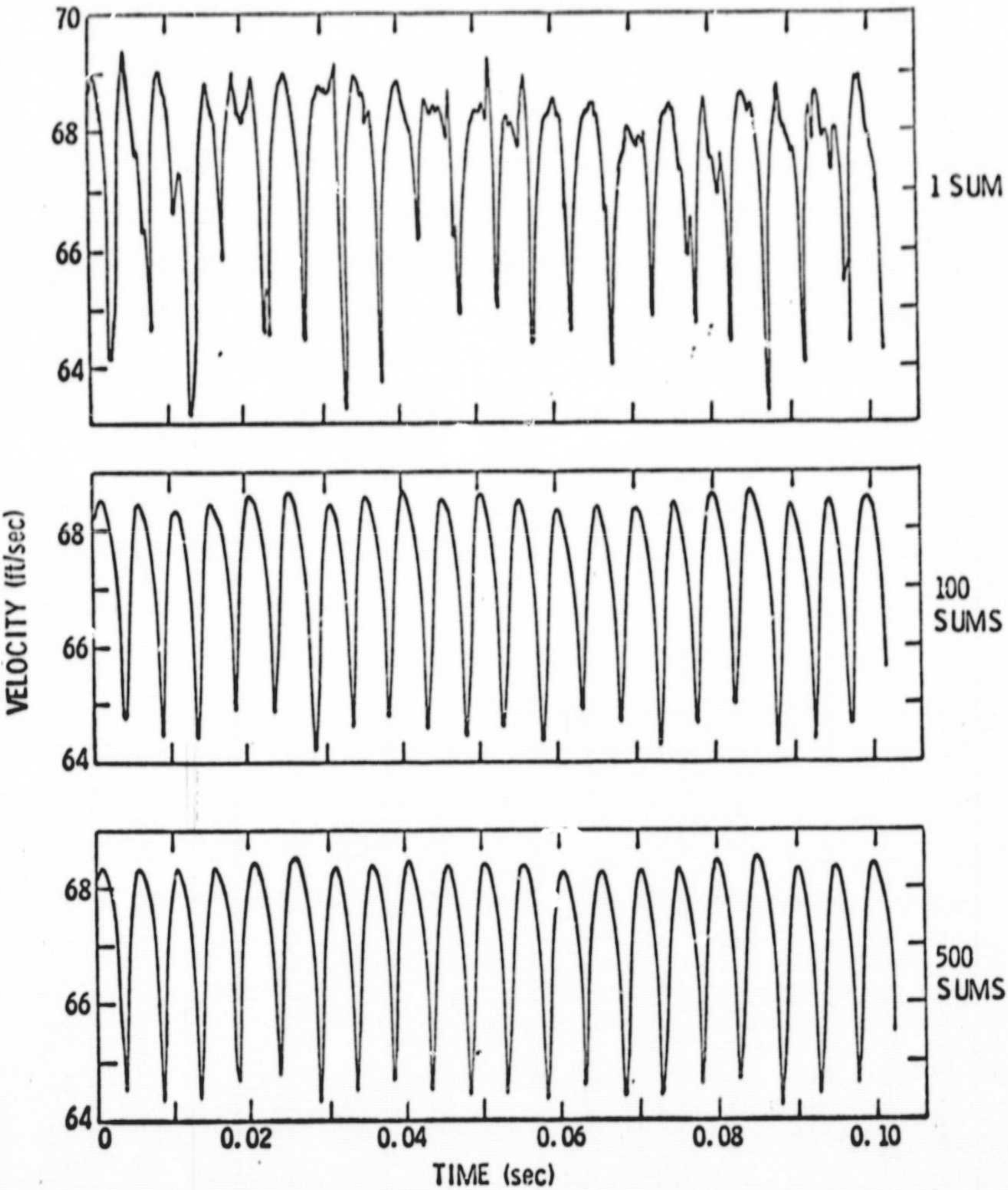


Figure 3: Effect of Summing in Data Analysis on the Rotor Wake Velocity Profile as Defined by a Hot-Film Probe Located at the Stator Inlet (The Period for One Rotor Revolution is 0.0594 Sec.)

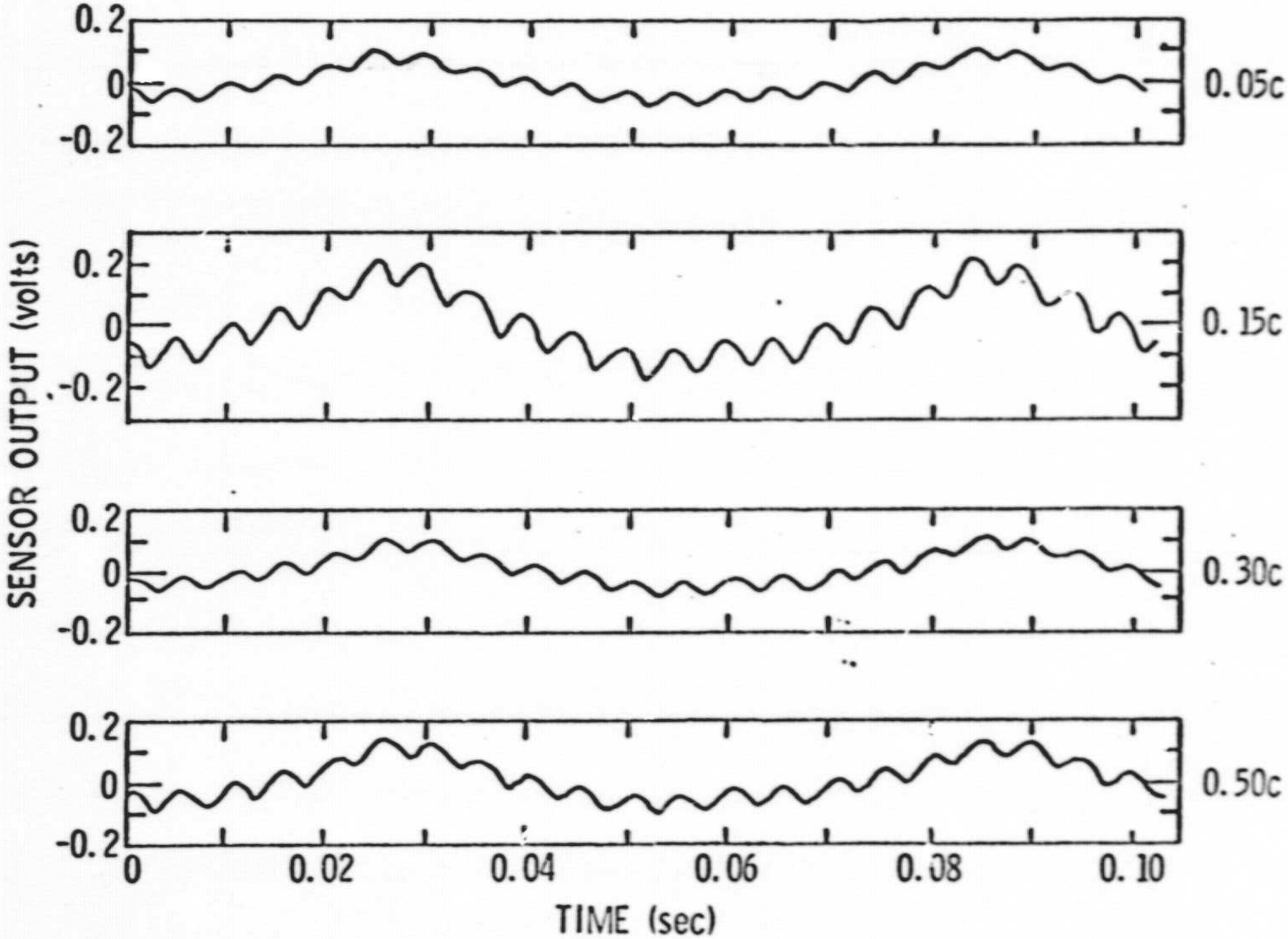


Figure 4: Pressure Sensor Output After 500 Sums as a Function of Time for Four Sensor Locations (The Period for One Rotor Revolution is 0.594 Sec.)